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TITLE: The acute effect of different frequencies of whole body vibration on countermovement
jump performance

BRIEF RUNNING HEAD: Vibration frequency & countermovement jumps

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ABSTRACT

Whole body vibration (WBV) has been shown to elicit acute and chronic improvements in neuromuscular function, however there is little conclusive evidence regarding an optimum protocol for acute WBV. The aim of this study was to compare the effects of acute exposure to different frequencies of WBV on countermovement jump (CMJ) height. Twelve recreationally trained males (age, 31 ± 8 years; height, 177 ± 12 cm; weight, 83.0 ± 6.9 kg) completed maximal CMJs pre- and post-WBV in a half-squat position for 30 seconds. In a blinded design with randomised testing order, participants were exposed on different days to frequencies of 0, 30, 35 and 40 Hz. Significant main effects were found for time (pre-to-post WBV, $P < 0.01$) and frequency*time interaction ($P < 0.01$), with post-hoc analysis highlighting that there was a significant mean improvement of 6 % in CMJ as a result of WBV at 40 Hz, but no significant change at other frequencies. This study demonstrates that for recreationally trained males an acute 30 s bout of vertical WBV at 40 Hz and 8mm peak to peak displacement significantly enhances explosive jumping performance in comparison to other frequencies. Acute vertical WBV for 30 seconds at 40 Hz may be incorporated into strength & conditioning training to enhance explosive power, however the exact mechanisms for improvements remain to be elucidated and further well-controlled investigations on chronic WBV training and using well-trained athletes are recommended.

Key Words: potentiation, explosive jumping, stretch reflex

INTRODUCTION

Whole-body vibration (WBV) is a recently developed training method that utilises neuromuscular properties to elicit a training response. WBV training typically consists of a participant standing, or performing various exercises, on a platform that generates sinusoidal vibration at a frequency of less than 100Hz with corresponding low peak to peak displacement (40). The oscillatory motion determines the peak to peak displacement (mm) while the repetition rate of oscillation determines the frequency (Hz). According to Wilcock et al. (40) and Crewther et al. (12), the combination of the peak to peak displacement, frequency and stance position determines the acceleration magnitude of vibration and hence transmission effect. The vibration causes a mechanical stimulus to be transmitted through the body, resulting in small rapid changes to muscle length, stimulating sensory receptors such as muscle spindles (8). This activates α -motor neurons and causes muscle contractions similar to a tonic vibration reflex (TVR) (16). The TVR is a response that occurs when vibration is applied directly to the muscle belly or tendon (11,35). This reflex is mostly characterised by the activation of muscle spindles, primarily through recruitment of Ia afferents and the activation of extrafusal muscle fibers through α -motor neurons. An improvement in physical performance after acute vibration has previously been attributed to neural factors such as: increased motor unit synchronization; stretch reflex potentiation; increased synergist muscle activity; and increased inhibition of the antagonist muscle (2). However, it is still unclear if this resultant increase in neuromuscular stimulation from WBV leads to an increase in athletic performance. Additionally, the connection between WBV and TVR has yet to be fully discussed or demonstrated in the literature (4).

Studies that analyse the acute effects of WBV on athletic performance have found positive effects on trained (5,9,22,31,37) and untrained (4,23,34) individuals for muscle strength and electromyographic (EMG) activity. Rittweger et al. (32) demonstrated a positive effect on neuromuscular recruitment patterns on untrained participants. Conversely, De Ruiter et al. (14) and Bullock et al. (6) found acute WBV had little or no effect on muscular activation, peak velocity, squat jump (SJ) and countermovement jump (CMJ) performance in untrained and trained individuals respectively. The actual mechanisms that are responsible for reported increases in strength and power are unclear; however, WBV may potentially provide additional training stimulus for athletes.

Indeed, the effects of chronic WBV training lasting from 5 weeks to 8 months have been documented, with some contradictory findings. Previous studies conducted on trained (3,35) and untrained (16,17,25,36,38) participants, found positive effects of chronic WBV on parameters of athletic performance such as jump height or muscular strength. Van den Tillaar (39) found that chronic WBV could have a positive effect on hamstring flexibility in untrained individuals. Conversely, De Ruiter et al. (15), and a review by Norlund & Thorstensson (30) found no difference in performance after chronic WBV on untrained or trained individuals. A recent review of chronic vibration training conducted by Wilcock et al. (40) found some evidence suggesting WBV training may provide a small benefit to maximal strength and power in trained athletes; however speed does not seem to be enhanced by WBV training. Furthermore, the optimum protocols and underpinning mechanisms for any improvements following chronic WBV training need to be explored.

Through the addition of vibration to exercise, the demands on the neuromuscular system may increase significantly and the adaptation that occurs can lead to a large increase in strength (27). For example, it is thought that acute WBV may be a plausible warm-up procedure for increasing vertical jump height, and should be considered by strength and conditioning coaches (11). Mester et al. (27) also stated that even with a relatively short training period the increase in performance could be caused more through a neuro-physiological adaptation than any morphological changes as a result of training. It is through these adaptations that both acute and chronic WBV exposure aim to elicit beneficial effects and so further exploration of acute responses to WBV and associated mechanisms should help to inform prescription of chronic WBV protocols.

Current research points to an increase in muscle power and strength after both chronic and acute vibration training, although protocols in the previously mentioned studies have utilised frequencies and peak to peak displacements ranging from 30 - 50 Hz and 4 - 12 mm respectively. Vibration training protocols vary significantly from a single 30 second WBV exposure (11) to 10 repetitions of 60 second WBV (5). The majority of WBV platforms allow for multiple settings of peak to peak displacement and frequency, leading to many possible combinations and resulting accelerations. This makes the prescription of safe, effective and validated vibration training protocols, as well as comparison and interpretation of results to evaluate the effectiveness of vibration, very difficult. These protocols have not yet been established (10). The purpose of this study was therefore to examine the influence of differing frequencies (0, 30, 35 and 40 Hz) at set peak to peak displacement during 30 second exposure to vertical WBV, on acute measures of CMJ performance in recreationally trained males. It is hypothesised that acute WBV exposure

will significantly enhance CMJ performance compared to no WBV, and furthermore that the magnitude of response will be significantly dependent on the frequency used.

METHODS

Experimental Approach to the Problem

This investigation focussed on the effects of manipulating frequency during acute WBV exposure. Therefore, frequency is the independent variable and CMJ height the dependent variable. To minimise the effect of inter-individual differences and eliminate potential order effects a single-blinded repeated-measures cross-over study design was used.

All participants attended a familiarisation session, where they were instructed in the correct squat position, and the correct technique for a CMJ. Participants then completed four randomised testing sessions – 30 Hz vibration, 35 Hz vibration, 40 Hz vibration or 0 Hz vibration (CONT) with at least one week between each session. After a standardised 5-minute cycle ergometer warm-up, baseline measurements of CMJ were conducted. At least 2 trials were conducted in order to establish an accurate baseline, with additional tests conducted if the trials were not within 5 % of each other. A 3 minute rest was allowed between each effort for adequate recovery. Participants then adopted the same half squat position during all of the experimental and control interventions and underwent 30 seconds of WBV at the allocated frequency (0 Hz for CONT) on the vibration platform before repeating the CMJ. Peak jump height readings were taken as the better of 2 trials. Protocols from previous studies (9,11,15) were followed to ensure standardisation of body position on the vibration platform and CMJ performance measures.

Subjects

The study involved 12 recreationally active men (age, 31 ± 8 years; height, 177 ± 12 cm; mass, 83.0 ± 6.9 kg), defined as taking part in regular physical activity (at least twice per week) and with some experience of resistance exercise, but not following a structured strength & conditioning program designed by an accredited coach. During the first visit, each participant read and signed a health status questionnaire to confirm study eligibility. If inclusion criteria were met, participants were informed about the study procedure and its possible risks and then provided written consent. The research was approved by the University of Edinburgh, Moray House School of Education Ethics Committee. No participants suffered from any contra-indications to WBV (19). Participants were blinded as to the aim of the study and the WBV frequencies used throughout the study, and were randomly allocated to each vibratory intervention before testing.

Procedures

The application of the vibration treatment was conducted using a vertical oscillating vibration plate (Nemes LS Bosco System, Rieti, Italy). The peak to peak displacement of the vibration platform was set at 8 mm and loading was carried out in a half-squat position with foot position standardised as shoulder-width apart and a visually monitored knee angle of 100° which was held constant throughout the 30-second exposure and across all experimental conditions, in accordance with previous studies (6,9,11). The control trial adopted the same position on the vibration plate for the same duration, however the plate was turned off.

Participants set up for the CMJ in a standing position on a portable jump mat (Just Jump Switch mat, Probotics Inc. Huntsville, Al, USA) with their hands placed on their hips. After instruction, participants initiated the jump via a downwards countermovement to a visually monitored knee angle of approximately 100°. Participants were then instructed to keep hand position constant throughout the jump and encouraged to reach a maximum explosive jump height with every attempt, according to protocols established previously (2,11). The outcome measure from the CMJ was jump height (cm).

Statistical Analyses

From other studies examining the effect of WBV frequency on CMJ performance (4) the *a priori* sample size was estimated as 12 with power of 0.8. Individual scores for pre-vibration CMJ height for each trial (CONT, 30, 35 and 40 Hz) were subjected to measures of reliability to determine the mean and standard deviation for pre-vibration CMJ, the change in mean, intraclass correlation (ICC), typical error (% CV) and confidence levels (%) using methods advocated by Hopkins (21). These values are presented in Table 1.

Insert Table 1 about here

The effect of the different vibration interventions on jump height was analyzed by means of a 2-way repeated measures ANOVA (frequency (0, 30, 35, 40 Hz) x time (pre and post)), following data checks for normality and sphericity (Mauchly's test). Where a main effect *F*-value was found to be significant, post-hoc paired t-tests with Bonferroni correction were used to locate the significant differences. Partial Eta Squared values were calculated as effect sizes: small effect sizes are considered $r = 0.1$; moderate effect sizes are considered $r = 0.3$; large effects sizes are

considered $r = 0.5$; very large effect sizes are considered $r = 0.7$; and near perfect effect sizes are considered $r = 0.9$ (21). All analysis was performed with the use of a statistical software package (SPSS version 14.0 for Windows, SPSS Inc., Chicago, IL). Significance level was set as $P < 0.05$.

RESULTS

Mean (+ SD) jump height results are presented in Figure 1. There was no significant main effect for vibration frequency ($F_{(3,33)} = 0.24$, $P = 0.87$), with a small effect size ($r = 0.15$). There was, however, a significant main effect for time ($F_{(1,11)} = 11.86$, $P < 0.01$), with a very large effect size ($r = 0.72$), and a significant frequency*time interaction effect ($F_{(3,33)} = 8.51$, $P < 0.01$), with a large effect size ($r = 0.66$). Post-hoc analysis revealed that only at a frequency of 40 Hz was there a significant difference from pre- to post-vibration (average 6.9 % increase: $t_{(11)} = 5.93$, $P < 0.001$), compared to non-significant pre- to post-vibration differences of -0.2 % ($P = 0.83$), 2.3 % ($P = 0.11$) and 1.1 % ($P = 0.29$) at 0, 30 and 35 Hz respectively.

Insert Figure 1 about here

All participants completed the study protocol with no reports of adverse side effects. Participants experienced the vibration loading as enjoyable but not fatiguing.

DISCUSSION

This study has demonstrated that acute vertical WBV can result in a significant increase in CMJ performance in recreationally active individuals, although this improvement is dependent on the frequency of WBV adopted. The reported significant impact of vibration frequency on CMJ performance, with 40 Hz significantly better than 30 Hz, 35 Hz and a 0 Hz position-matched control, is in agreement with some existing research but in contrast to other studies. The hypotheses that WBV would have a significant effect, and that this effect would be dependent on frequency, cannot be rejected. These results would suggest that for vertical NEMES WBV at a peak to peak displacement of 8mm, a frequency of at least 40 Hz is required for acute benefits (e.g. warm-up) for training or performance in recreationally active individuals and therefore more likely to induce chronic adaptations.

Before considering the impact of vibration frequency, it is worth summarising the current theories that could explain significant improvements in CMJ performance reported here and elsewhere. The exact mechanisms responsible for the improvements in neuromuscular performance following WBV are, as yet, not fully known (30). Initially, Eklund & Hagbarth (18) suggested that vibration-induced rapid changes in muscle length evokes the TVR, i.e. muscle spindle activation which may cause an improvement of α motoneuron inflow and enhancement of the Ia neuron stretch-reflex loop (8). Indeed, improvements in neuromuscular performance post-WBV have been associated with neuromuscular facilitation supported by EMG (9). For example, increased motor unit recruitment of previously inactive Type II motor units (24) or reducing the recruitment threshold of these types of motor units (17) may alter normal recruitment patterns (28). A further plausible explanation is post-activation potentiation (PAP)

(33), which is an enhancement of neuromuscular performance following high-intensity contractions (e.g. 20). This is proposed to reflect a net balance of negative fatiguing effects and positive potentiation caused by increases in α motoneuron excitability (similar to TVR), as well as increased sensitivity of contractile proteins to calcium (20).

The findings of the present study are in support of many other studies showing significant enhancement of jumping performance following acute WBV (2,3,4,11,38) but it is important to note these studies involved varying WBV delivery systems, WBV parameters and participants. The enhancement in jumping performance is most likely due to the above mechanisms, however, other studies have found no significant benefit (6,8). There are a number of arguments that could explain these discrepancies. Firstly, there are a wide range of vibratory protocols (26) used in the existing studies and this was a main rationale for the current investigation on the influence of vibration frequency. Although, in addition to manipulating frequency, it is important to also appreciate the impact of peak to peak displacement, WBV exposure duration and recovery periods, which were all carefully standardised in the current study. Secondly, there are a range of outcome measures used and the current study has focussed on CMJ as it evokes a stretch reflex component which is likely to be influenced by WBV exposure (17). The use of CMJ is also justified as we have demonstrated reliability is good to excellent (ICC of 0.93 – 0.98 and CV of 3.8 – 6.6 %). Thirdly, body position in previous studies varies considerably though it is known that stretched muscles are more sensitive to vibratory stimulation (18) and contract more strongly (9), yet some previous studies have not controlled for this stretching effect. This study was conducted with the participants standing in a half squat position on the vibration platform, therefore the quadriceps muscle group would be in a stretched position to expose the vastus

muscle group to stimulation (9). The current study clearly shows that the combination of stretching and vibration were responsible for the neuromuscular improvement following acute WBV exposure, as the 0 Hz condition showed no significant improvement. Fourthly, the vibration exposure and physiological effect differs depending on the type of vibrating platform used (1). Since the present study utilised a vertical WBV platform and recreationally trained participants, comparisons with other studies which utilised triplanar or pivotal WBV mechanics and participants with varied training status should be made with caution. As the response to WBV may vary within and across different populations (22), which may contribute to the frequency-dependency. For example, Issurin and Tennenbaum (22) found that the average gain in maximal power due to vibratory stimulation was greater in elite athletes, due to higher sensitivity of muscle receptors of elite athletes to any additional stimulation. Also, PAP has been shown to have greater effect in resistance trained individuals (33). However, one could argue that since resistance training improves motor unit recruitment then untrained or less trained individuals may have greater potential for improvements.

A possible theory which may explain why the present study found that only 40 Hz resulted in a significant increase in CMJ performance, is that TVR has been reported to be proportional to vibration frequency (7), so an increase in vibration frequency can cause a proportional increase in muscle tension. Similarly, PAP has been demonstrated to depend on the intensity of contractile history (20), so lower frequencies may be insufficient to potentiate performance. However, Da Silva et al. (13) found that 30 Hz, and not 40 Hz, produced significant acute increases in jump performance. That study involved 6 sets of 60 second WBV exposures compared to 1 set of 30 seconds in the present study, so the net increase in volume of vibratory

stimulus (6 x 60 s vs. 1 x 30 s) may have induced muscular fatigue that offsets any neuromuscular facilitation at 40 Hz, yet is sufficient to cause improvements at 30 Hz.

Alternatively, inconsistency related to frequency dependency, as well as overall effects of acute WBV exposure, may relate to individual differences in response to WBV. Indeed, across the literature large inter-subject variability has been found in EMG response from different WBV frequencies (17). These may be explained by muscle tuning theory (29) which suggests the presence of individual differences in intrinsic muscle characteristics such as mechanoreceptor locations and type II fiber percentages (9). These characteristics would influence the individuals' capacity to dampen vibration. As some studies may have used the optimal frequency for the participants, others may not have, or to varying degrees with individuals, resulting in the overall effect being masked by group mean comparisons.

The present study and existing literature suggest that individualising WBV protocols in terms of frequency should elicit the most beneficial response. This would involve the use of EMG recording to monitor the response to each different frequency, with the aim of detecting a higher EMG response to a particular individualised frequency. This may be possible in elite well trained athletes and may provide a more effective method of utilising WBV. Future studies should be repeated on elite athletes with a history of strength training to determine if they would require higher vibration parameters to elicit the same effect, or to evaluate the extent of this individualisation. In recreationally trained and the general population, where such EMG opportunities are unlikely, the present study argues that 40 Hz of vertical WBV at peak to peak displacement of 8 mm may be utilised for warm-up, or potentially to induce adaptations with

chronic WBV exposure, to increase neuromuscular performance in explosive jumping activities. Lamont et al (25) found that the application of chronic WBV, at a frequency of 50 Hz before and in-between sets of resistance training, produced a positive effect on power adaptations in a similar population to the current study, so further training studies into optimum chronic WBV protocols are clearly required.

In conclusion, acute vertical WBV at a frequency of 40 Hz and peak to peak displacement of 8 mm produced significant increases in CMJ performance of recreationally-trained participants. It may be that this frequency was most appropriate to elicit the proposed neuromuscular mechanisms responsible for the increase in performance; however, there is a case for further investigating individualisation with regards WBV training prescription.

PRACTICAL APPLICATIONS

Whole-body vibration using a vibration platform may be administered prior to, or in between, performing ballistic, strength and power exercises as a warm-up or during training in order to elicit greater performance gains. However, the details of the best vibration protocols have yet to be agreed on as the effects depend on the vibration frequency, amplitude, duration, body position adopted and type of vibration platform. For elite athletes, current research would promote the use of EMG to identify the best frequency, however this will not be practical for many other populations. Therefore, the findings of the current study are important as they show that in recreational participants using a vertical vibration platform, acute exposure to WBV at 40 Hz and peak to peak displacement of 8 mm is sufficient to significantly improve countermovement jump performance.

REFERENCES

1. Abercromby, AF, Amonette, WE, Layne, CS, McFarlin, BK, Hinman, MR, and Paloski, WH. Variation in neuromuscular responses during acute whole-body vibration exercise. *Med Sci Sports Exerc* 39: 1642-1650, 2007.
2. Adams, JB, Edwards, D, Serviette, D, Bedient, AM, Huntsman, E, Jacobs, KA, Rossi, GD, Roos, BA, and Signorile, JF. Optimal frequency, displacement, duration, and recovery patterns to maximize power output following acute whole-body vibration. *J Strength Cond Res* 23: 237-245, 2009.
3. Annino, G, Padua, E, Castagna, C, Di Salvo, V, Minichella, S, Tsarpela, O, Manzi, V, and D'Ottavio, S. Effect of whole body vibration training on lower limb performance in selected high-level ballet students. *J Strength Cond Res* 21: 1072-1076, 2007.
4. Bazett-Jones, DM, Finch, HW, and Dugan EL. Comparing the effects of various whole body vibration accelerations on counter-movement jump performance. *J Sports Sci Med* 7: 144-150, 2008.
5. Bosco, C, Colli, R, Introini, E, Cardinale, M, Tsarpela, O, Madella, A, Tihanyi, J, and Viru, A. Adaptive responses of human skeletal muscle to vibration exposure. *Clin Physiol* 19: 183-187, 1999.
6. Bullock, N, Martin, DT, Ross, A, Rosemond, CD, Jordan, MJ, and Marino, FE. Acute effect of whole-body vibration on sprint and jumping performance in elite skeleton athletes. *J Strength Cond Res* 22: 1371-1374, 2008.
7. Burke, D, Hagbarth, KE, Lofstedt, L, and Wallin, BG. The responses of human muscle spindle endings to vibration of non-contracting muscles. *J Physiol* 261: 673-693, 1976.
8. Cardinale, M, and Bosco, C. The use of vibration as an exercise intervention. *Exerc Sport Sci Rev* 31: 3-7, 2003.
9. Cardinale, M, and Lim, J. Electromyography activity of vastus lateralis muscle during whole-body vibrations of different frequencies. *J Strength Cond Res* 17: 621-624, 2003.
10. Cardinale, M, and Wakeling, J. Whole body vibration exercise: are vibrations good for you? *Br J Sports Med* 39: 585-589, 2005.
11. Cormie, P, Deane, RS, Triplett, NT, McBride, JM. Acute effects of whole-body vibration on muscle activity, strength, and power. *J Strength Cond Res* 20: 257-261, 2006.
12. Crewther, B, Cronin, J and Keogh, J. Gravitational forces and whole body vibration: implications for prescription of vibratory stimulation. *Phy Ther Sport* 5: 37-43, 2004.
13. Da Silva, ME, Nunez, VM, Vaamonde, DM, Fernandez, JM, Poblador, MS, Garcia-Manso, JM, and Lancho, JL. Effects of different frequencies of whole body vibration on muscular performance. *Biology of Sport* 23: 267-282, 2006.
14. de Ruiter, CJ, van der Linden, RM, van der Zijden, MJ, Hollander, AP, and de Haan, A. Short-term effects of whole-body vibration on maximal voluntary isometric knee extensor force and rate of force rise. *Eur J Appl Physiol* 88: 472-475, 2003.
15. de Ruiter, CJ, Van Raak, SM, Schilperoort, JV, Hollander, AP, and de Haan, A. The effects of 11 weeks whole body vibration training on jump height, contractile properties and activation of human knee extensors. *Eur J Appl Physiol* 90: 595-600, 2003.
16. Delecluse, C, Roelants, M, and Verschueren, S. Strength increase after whole-body vibration compared with resistance training. *Med Sci Sports Exerc* 35: 1033-1041, 2003.

17. Di Giminiani, R, Tihanyi, J, Safar, S, and Scrimaglio, R. The effects of vibration on explosive and reactive strength when applying individualized vibration frequencies. *J Sports Sci* 27: 169-177, 2009.
18. Eklund, G and Hagbarth, KE. Normal variability of tonic vibration reflexes in man. *Exp Neurol* 16: 80-92, 1966.
19. Galileo. Galileo contraindications - the elite in vibration training. Available at <http://www.galileoouk.co.uk/contra.html> Accessed 2009.
20. Hodgson, M, Dochery, D, and Robbins, D. Post-activation potentiation. *Sports Med* 35: 585-595, 2005.
21. Hopkins, WG. Reliability from consecutive pairs of trials (Excel spreadsheet) Available at: <http://sportsci.org/resource/stats/index.html> Accessed, 2009.
22. Issurin, VB, and Tenenbaum, G. Acute and residual effects of vibratory stimulation on explosive strength in elite and amateur athletes. *J Sports Sci* 17: 177-182, 1999.
23. Jacobs, PL, and Burns P. Acute enhancement of lower-extremity dynamic strength and flexibility with whole-body vibration. *J Strength Cond Res* 23:51-57, 2009.
24. Jordan, MJ, Norris, SR, Smith, DJ, and Herzog, W. Vibration training: an overview of the area, training consequences, and future considerations. *J Strength Cond Res* 19: 459-466, 2005.
25. Lamont, HS, Cramer, JT, Bemben, DA, Shehab, RL, Anderson, MA, and Bemben, MG. Effects of 6 weeks of periodized squat training with or without whole-body vibration on short-term adaptations in jump performance within recreationally resistance trained men. *J Strength Cond Res* 22: 1882-1893, 2008.
26. Lorenzen, C, Maschette, W, Koh, M, and Wilson, C. Inconsistent use of terminology in whole body vibration exercise research. *J Sci Med Sport* doi:10.1016/j.jsams.2008.06.008, 2008.
27. Mester, J, Spitzenfeil, P, Schwarzer, J, and Seifriz, F. Biological reaction to vibration--implications for sport. *J Sci Med Sport* 2: 211-226, 1999.
28. Misch, M, and Cardinale, M. The effects of a 28-Hz vibration on arm muscle activity during isometric exercise. *Medicine and Science in Sports and Exercise* 41: 645-652, 2009.
29. Nigg, BM, and Wakeling, JM. Impact forces and muscle tuning: a new paradigm. *Exerc Sport Sci Rev* 29: 37-41, 2001.
30. Nordlund, MM, and Thorstensson, A. Strength training effects of whole-body vibration? *Scand J Med Sci Sports* 17: 12-17, 2007.
31. Rhea, MR, and Kenn, JG. The effect of acute applications of whole-body vibration on the iTonic platform on subsequent lower-body power output during the back squat. *J Strength Cond Res* 23: 58-61, 2009.
32. Rittweger, J, Mutschelknauss, M, and Felsenberg, D. Acute changes in neuromuscular excitability after exhaustive whole body vibration exercise as compared to exhaustion by squatting exercise. *Clin Physiol Funct Imaging* 23: 81-86, 2003.
33. Robbins, DW. Postactivation potentiation and its practical applicability: a brief review. *J Strength Cond Res* 19: 453-458, 2005.
34. Roelants, M, Verschueren, SM, Delecluse, C, Levin, O, and Stijnen, V. Whole-body-vibration-induced increase in leg muscle activity during different squat exercises. *J Strength Cond Res* 20: 124-129, 2006.

35. Ronnestad, BR. Comparing the performance-enhancing effects of squats on a vibration platform with conventional squats in recreationally resistance-trained men. *J Strength Cond Res* 18: 839-845, 2004.
36. Silva, HR, Couto, BP, and Szmuchrowski, LA. Effects of mechanical vibration applied in the opposite direction of muscle shortening on maximal isometric strength. *J Strength Cond Res* 22: 1031-1036, 2008.
37. Stewart, JA, Cochrane, DJ, and Morton RH. Differential effects of whole body vibration durations on knee extensor strength. *J Sci Med Sport* 12: 50-53, 2009.
38. Torvinen, S, Kannus, P, Sievanen, H, Jarvinen, TA, Pasanen, M, Kontulainen, S, Nenonen, A, Jarvinen, TL, Paakkala, T, Jarvinen, M, and Vuori, I. Effect of 8-month vertical whole body vibration on bone, muscle performance, and body balance: a randomized controlled study. *J Bone Miner Res* 18: 876-884, 2003.
39. van den Tillaar, R. Will whole-body vibration training help increase the range of motion of the hamstrings? *J Strength Cond Res* 20: 192-196, 2006.
40. Wilcock, IM, Whatman, C, Harris, N, and Keogh, JW. Vibration training: could it enhance the strength, power, or speed of athletes? *J Strength Cond Res* 23: 593-603, 2009.

Figure Legend

FIGURE 1. Mean (+ SD) CMJ height (cm) pre- and post-30 seconds of WBV exposure at 0, 30, 35 and 40 Hz frequencies. * indicates a significant pre-to-post vibration difference in CMJ height at this frequency ($P < 0.001$).

Table Legend

TABLE 1. Reliability data for pre-WBV CMJ height performances at different frequencies: mean CMJ height (cm); standard deviation (SD); change in the mean (cm) (with confidence limit) compared to control trial at 0 Hz; intraclass correlation coefficients (ICC); percentage coefficients of variation (% CV).

Figure 1

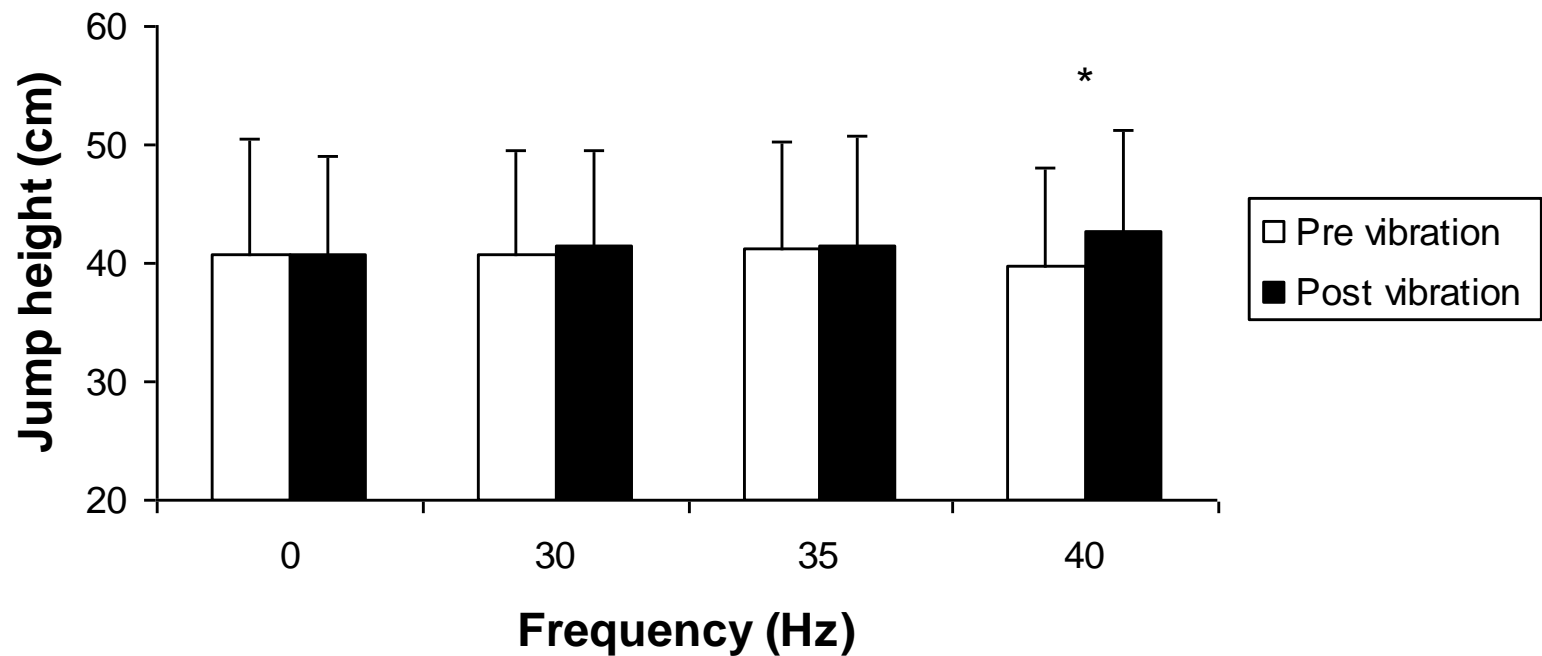


Table 1 – Reliability Data

	0 Hz	30 Hz	35 Hz	40 Hz
Mean in cm (SD)	40.8 9.6	40.6 8.8	41.1 9.0	39.9 8.2
Change in mean in cm (confidence limit)		-0.13 (-2.12 – 1.87)	0.49 (-1.66 – 1.64)	-1.28 (-2.61 – 0.05)
ICC		0.93	0.98	0.97
% CV		6.6%	3.8%	4.7%